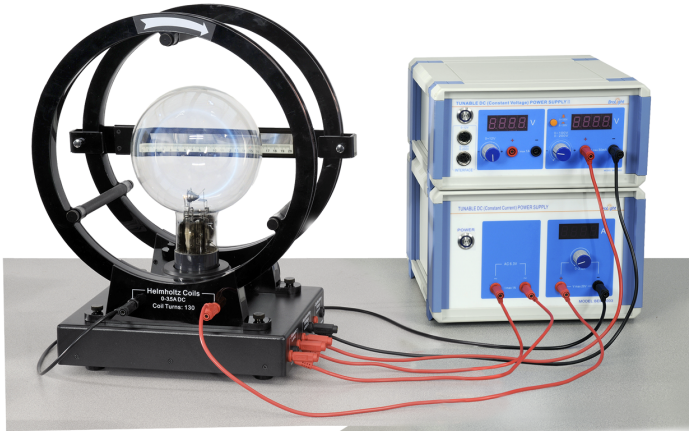
Electron Charge-to-Mass Ratio (SE-9629)

Introduction

The e/m apparatus (Electron Charge-to-Mass Ratio) provides a simple method for measuring *e/m*, the charge to mass ratio of the electron. The method is similar to that used by J.J. Thomson in 1897. A beam of electrons is accelerated through a known potential, so the velocity of the electrons is known. A pair of Helmholtz coils produces a uniform and measurable magnetic field at right angles to the electron beam. This magnetic field deflects the electron beam in a circular path.



The e/m apparatus also has deflection plates that can be used to demonstrate the effect of an electric field on the electron beam. This can be used as a confirmation of the negative charge of the electron, as well as to demonstrate how an oscilloscope works.

A unique feature of the e/m tube is that the socket rotates, allowing the electron beam to be oriented at any angle (in the range of ±30 degrees) with respect to the magnetic field from the Helmholtz coils. You can therefore rotate the tube and examine the vector nature of the magnetic forces on moving charged particles.

What's included

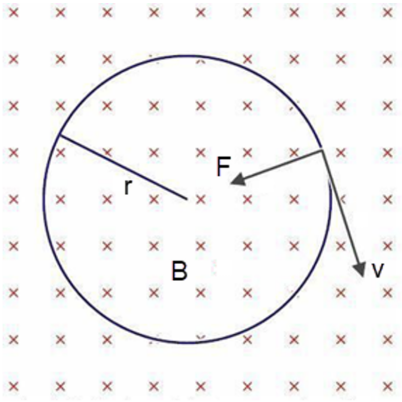
- e/m Tube (SE-9659)
- Helmholtz Coils and Base (SE-9626)
- Tunable DC Power Supply (Constant Current) (SE-9622)
- Tunable DC Power Supply II (Constant Voltage) (SE-9644)

Background information

In 1887, J.J. Thomson showed that the mysterious cathode rays were actually negatively charged particles, thereby discovering the electron. In the same year, he measured the *specific charge* (e/m) of the cathode ray particles, providing the first measurement of one of the fundamental constants of the universe. The specific charge is defined as the charge per unit mass of the particle. Thomson discovered that the value of e/m was independent of the gas used, as well as independent of the nature of the electrodes.

Principle of the experiment

In the e/m tube, the electrons move along a circular path in a uniform magnetic field. The tube contains helium gas at a precisely set pressure. The gas atoms are ionized along the length of the circular path due to collisions with electrons. As a result, they are excited and emit light, thereby indirectly making the circular path of the electrons visible. The radius of the path can then be measured directly with a ruler. Since the magnetic field *B* and the accelerating voltage *U* of the electron gun are known, it is possible to calculate the specific charge *e/m* of an electron from the radius *r* of the circular path.



An electron moving with velocity *v* in a direction perpendicular to a uniform magnetic field *B* experiences a Lorentz force *F* in a direction perpendicular to both the velocity and the magnetic field:

$$F = evB$$

where *e* is the charge on an electron. This gives rise to a centripetal force on the electron in a circular path with radius *r*, as given by:

$$F = \frac{mv^2}{r}$$

where *m* is the mass of an electron. Thus:

$$evB = \frac{mv^2}{r}$$

The velocity *v* depends on the accelerating voltage *U* of the electron gun, as given by:

$$v^2 = \frac{2Ue}{m}$$

Therefore, the specific charge of an electron is given by:

$$\frac{e}{m} = \frac{2U}{B^2r^2}$$

If we measure the radius of the circular orbit in each case for different accelerating voltages *U* and different magnetic fields *B*, then, according to the equation, the measured values can be plotted in a graph of B^2r^2 versus $2U$ as a straight line through the origin, with slope *e/m*.

Safety information

WARNING: To avoid possible electric shock or personal injury, follow these guidelines.

- Clean the equipment *only* with a soft, dry cloth.
- Before use, verify that the apparatus is not damaged. *Do not use the apparatus if it is damaged.*
  - Always inspect the case for signs of damage before using the equipment. Pay particular attention to the insulation surrounding the connectors.
- **Do not** disconnect the power cord safety ground feature.
- When plugging in the apparatus, always plug it into a grounded (earthed) outlet.
- Do not use the product in any manner that is not specified by the manufacturer.
- Do not install substitute parts or perform any unauthorized modification to this product.
- Line and Current Protection Fuses: To ensure protection against fire, replace the line fuse and the current-protection fuse *only* with fuses of the specified type and rating.
- Main Power and Test Input Disconnect: Unplug instrument from wall outlet, remove power cord, and remove all probes from all terminals *before* servicing. Only qualified, service-trained personnel should remove the cover from the instrument.
- Immediately stop using the equipment if it operates abnormally, as protection may be impaired. When in doubt, have the equipment serviced.
- Do not operate the equipment under wet conditions, or under conditions where explosive gas, vapor, or dust are present.
- Do not apply more than the rated voltage (as marked on the apparatus) between terminals, or between any terminal and ground.
- When servicing the equipment, only use specified replacement parts.
- Use caution when working with voltages above 30 V AC rms, 42 V peak, or 60 V DC. Such voltages pose a shock hazard.
- To avoid electric shock, do not touch any bare conductor with hands or skin.
- Adhere to all local and national safety codes. Individual protective equipment must be used to prevent shock and arc blast injury where hazardous live conductors are exposed.
- *Keep in mind:* If a dangerous voltage is applied to an input terminal, then the same voltage may occur at **all** other terminals.

Assembly

Assemble the base

1. Use the screws from the mounting hardware to fasten the two Helmholtz coils on the platform so that the terminals on the coils face toward the outside.
2. Fasten the three support rods from the mounting hardware between the two Helmholtz coils.
3. Mount the mirrored scale on one of the Helmholtz coils so that the mirror reflects toward the e/m tube coil. Tighten the screws on the ends of the mirrored scale to hold it in place on the coil.
4. Holding the e/m tube by its base, align the tab on the tube with the notch in the socket. Turn the tube in the socket until the tab slips into the notch, then push the tube into the socket. Make sure that the tube is firmly in place.

WARNING: Avoid touching the glass bulb of the tube. Touch *only* the plastic part below the glass bulb. Do not expose the tube to any mechanical stress or strain. Handle with care.

Figure 1. The fully assembled base.

Connect cables and cords

DANGER: High voltage is applied to the e/m tube. *Avoid contact with any part of the body.*

- Only use shrouded patch cords for connections.
- Make sure that the power supplies are OFF *before* making the connections.
- Make sure that the power supplies are OFF *before* installing or replacing the e/m tube.

IMPORTANT: Make sure that the AC voltage switches on the power supplies are set for your AC voltage level.

NOTE: Before connecting any cords or cables, be sure that all power switches on the Power Supplies are in the OFF position and all voltage controls are turned fully counterclockwise.

Connect the cables and cords as described in the steps below to finish setting up the e/m apparatus. The steps are labeled in the diagram in Figure 2.

❶ On the Tunable DC (Constant Voltage) Power Supply II, connect the positive terminal of the **200 V DC** output to the **Accelerating Voltage** positive terminal on the platform. Connect the negative terminal of the 200 V DC output to the Accelerating Voltage negative terminal.

❷ On the Tunable DC (Constant Current) Power Supply, connect both terminals of the **AC 6.3 V** output to the **Filament** terminals on the platform.

❸ On the Tunable DC (Constant Current) Power Supply, connect the *positive* terminal of the **3.5 A** output to the *red* terminal on the **front Helmholtz coil**.

❹ Connect the *black* terminal of the **front Helmholtz coil** to the *black* terminal of the **rear Helmholtz coil**.

❺ Connect the *red* terminal of the **rear Helmholtz coil** to the *negative* terminal of the **3.5 A** output on the Tunable DC (Constant Current) Power Supply.

❻ (*Not pictured*) Connect the power cords to the power supplies, then use these cords to connect the power supplies to an electrical outlet.

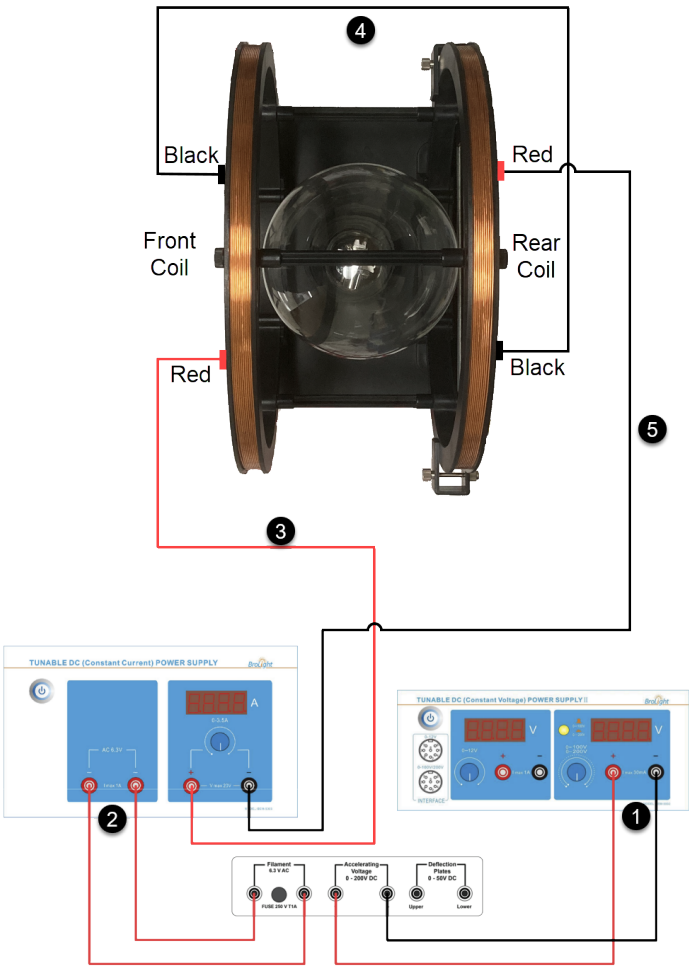


Figure 2. Connecting the coils, e/m Tube, and power supplies together.

Experiment procedure

Adjust voltages and currents

Before beginning the experiment, be sure that all power switches on the Power Supplies are in the OFF position and all voltage controls are turned fully counterclockwise.

NOTE: If you are not using the e/m tube which was supplied with your apparatus, or if you are not sure if the tube has been replaced, see the **Accounting for older e/m tubes** section.

1. On the Tunable DC (Constant Voltage) Power Supply II, set the Voltage Range Switch to **0 - 200 V**.
2. For both power supplies, push in the Power Switch to the **ON** position.
3. Wait for about five minutes to allow the filament to heat up before proceeding.
4. On the Tunable DC (Constant Voltage) Power Supply II, set the **Accelerating Voltage** to **190 V DC** to make the electron beam appear.
5. On the Tunable DC (Constant Current) Power Supply, increase the current to the Helmholtz coils. Watch the electron beam and check to make sure that the beam

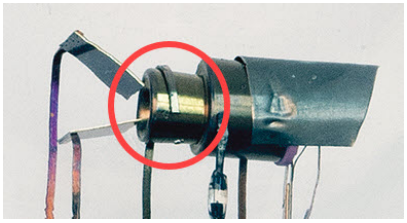
curves upward. Continue increasing the current until the electron beam forms a closed circle.

- If the electron beam does not deflect, reverse the polarity of one of the Helmholtz coils so current passes through both of the coils in the same direction.
- If the electron beam deflects downward, swap the connections on the 3.5 A output terminals on the Power Supply.
- If the electron beam forms a spiral, rotate the tube on the platform until a closed circle is formed. You may also need to rotate the platform to the right or left to align the magnetic field generated by the Helmholtz coils with Earth's magnetic field.

6. On the Tunable DC (Constant Voltage) Power Supply II, adjust the voltage output to the **Accelerating Voltage** to optimize the focus and brightness of the electron beam.

Accounting for older e/m tubes

Older models of the e/m tube require a slightly different setup procedure than those currently provided by PASCO. Take a moment to check your tube's electron emitter. Older e/m tubes feature a cylindrical electron gun, as shown below (circled in red), whereas the newer tubes feature a conical electron gun.



If your e/m tube does not match the image above, you may ignore this section. However, if you are using an older e/m tube, perform the following steps *in between* Steps 4 and 5 of the **Adjust voltages and currents** section:

1. Connect a wire between the ports for the upper and lower deflection plates, as shown in Figure 3.
2. Connect a wire between the **Accelerating Voltage** *positive* terminal and the **Deflection Plates** *upper* terminal to make the electron beam appear.

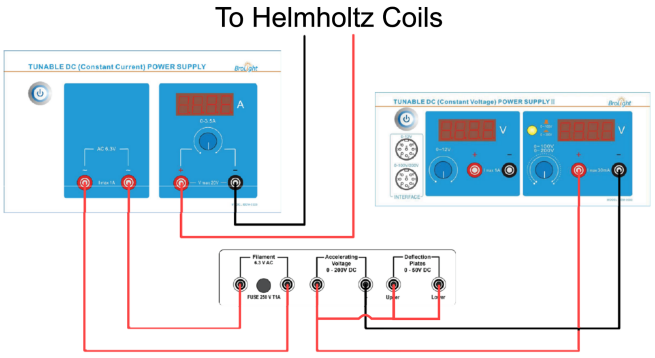


Figure 3. Cable setup for older e/m tubes.

Record data

1. Read the current display to find the current I_H through the Helmholtz coils. Record the value in Table 1.
2. Read the voltmeter and record the Accelerating Voltage *U* in Table 1.
3. Measure the radius *r* of the electron beam's circular path. Look through the e/m tube at the mirrored scale. To avoid parallax errors, move your head to align the electron beam in the tube with the reflection of the beam as you see it in the mirrored scale. Measure the radius of the electron beam path as you see it on both sides of the scale and average the results. Record the average radius in Table 1.
4. Collect additional trials of data using different accelerating voltages and current through the Helmholtz coils.

Table 1. Data

Trial	U (V)	I_H (A)	R (mm)	e/m (C/kg)	% error
1					
2					
3					
4					
5					

Analysis of e/m measurements

The magnetic field *B* generated in a pair of Helmholtz coils is proportional to the current I_H passing through a single coil. The constant of proportionality *k* can be determined from the coil radius *R* and the number of turns *N* on the coil with the following equation:

$$B = \frac{\left(\frac{4}{5}\right)^{\frac{3}{2}} \mu_0 N I_H}{R}$$

With this expression for *B*, the initial formula for e/m,

$$\frac{e}{m} = \frac{2U}{B^2 r^2}$$

becomes:

$$\frac{e}{m} = 2U \frac{\left(\frac{5}{4}\right)^3 R^2}{(\mu_0 N I r)^2}$$

In this experiment, *R* = 158 mm, *N* = 130 turns per coil, and $\mu_0 = 4\pi \times 10^{-7}$.

The accepted value of the charge-to-mass ratio *e/m* is **1.75×10^{11} C/kg**.

Demonstrations

Deflect the beam using an electric field
With no current in the Helmholtz coils, deflect the beam using the deflection plates:

- Connect a wire between the **Accelerating Voltage** *positive* terminal and the **Deflection Plates** *Upper* terminal to make the electron beam deflect upwards.
- Switch the wire to the **Deflection Plates** *Lower* terminal to make the electron beam deflect downwards.

Deflect the beam with a permanent magnet
Hold a permanent bar magnet near the tube to show the effect of a magnetic field on the electron beam. Switch between holding the north and south ends of the magnet near the beam.

Rotate the tube
Rotate the tube so that it is oriented at an angle with respect to the magnetic field from the Helmholtz coils. As you rotate the tube, observe how the beam deflection is affected.

Deflect the beam using Earth's magnetic field
With no magnet and no current in the Helmholtz coils, rotate the tube or the entire apparatus to see the deflection of the beam due to the Earth's magnetic field. Is the direction of the deflection of the beam as you expect?

Sample data

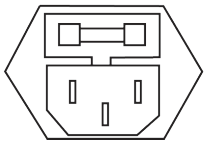
Table 2. Sample Data

Trial	U (V)	I_H (A)	R (mm)	e/m (C/kg)	% error
1	100	1.0	45.0	1.80×10^{11}	2.5
2	105	1.1	42.5	1.76×10^{11}	-0.3
3	110	1.2	40.0	1.74×10^{11}	-0.9
4	115	1.3	38.0	1.72×10^{11}	-2.2
5	120	1.4	35.5	1.78×10^{11}	0.9

Fuse replacement

WARNING: To reduce the risk of electric shock or damage to the instrument, turn the power switch OFF *and* disconnect the power cord before replacing a fuse.

1. Disconnect the power cord from the instrument.
2. Open the fuse cover and remove the fuse. The fuse is inside a tray above the AC power cord socket. Use a small screwdriver or other tool to pry the tray open.



3. Replace the fuse with another fuse of the same type (250 V T2A). One spare fuse is included inside the tray.
4. Reconnect the power cord and turn on the instrument.

Specifications and accessories

Visit the product page at pasco.com/product/SE-9629 to view the specifications and explore accessories. You can also download support documents from the product page.

Technical support

Need more help? Our knowledgeable and friendly Technical Support staff is ready to answer your questions or walk you through any issues.

Chat	pasco.com
Phone	1-800-772-8700 x1004 (USA) +1 916 462 8384 (outside USA)
Email	support@pasco.com

Regulatory information

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